Fermilab

TM-1069
1738.000

Energy Doubler Cryoloop Temperature Monitor System

Greg Pucci and Douglas Howard

October, 1981

I. General

The Cryoloop Temperature Monitor System is a fully electronic system designed to monitor temperature at key points in the Energy Doubler cryoloop system. It is used for cryoloop diagnostics, temperature studies, and cooldown valve control. Temperature monitoring points in each cryoloop are:

1) Each 10 relief port of quadrupole magnets

2) 10 input at turnaround box

3) 10 output of feedbox

4) He exhaust at turnaround box

5) LN_2 exhaust at turnaround box

The control electronics required to monitor temperature at the specified points in each cryoloop consists of the temperature transducers, a 24-channel current source module, a control module, and a 4-wire cable run between the temperature transducers and the current source module. The electronic modules are located in racks in each service building, with the current source module located in a standard NIM crate and the control module located in the refrigeration system Multibus crate. Each current source module can monitor temperature for up to 24 points in the cryoloop and the control module can interface with one or two current source modules.

The temperature transducers consist of two types of resistance thermometers: 1) pre-sorted standard carbon composition resistors, and 2) commercially available platinum resistance thermometers. Both types of thermometers provide temperature information by a known resistance vs. temperature calibration curve. The carbon composition resistors have good sensitivity between 4°K and 70°K, while the platinum resistors have good sensitivity between 70°K and 300°K. Both types of resistors have a resistance range of 18Ω to 100Ω over their useful temperature range.

The function of the Cryoloop Temperature Monitor System is to accurately measure resistance of the temperature transducers, digitize the result, and provide the information to the refrigeration system μC when requested. The system normally measures each of the 24 resistance thermometers associated with a current source module at a rate of once per second and stores that information into memory. With each new measurement of a particular channel, the old data is discarded. This mode of operation of the system is called the sequential mode.

An additional feature of the system is the ability to generate a "time plot" of a particular channel. That is, repeated measurements of one resistor can be made at specified intervals, and the information from 232 consecutive measurements can be stored in memory. This time plot mode is initiated by the μC, which needs only to provide the system with a time plot channel (specifying which resistor is to be plotted) and the time interval between measurements (ranging from 50 ms to 54 minutes in 50 mS increments) in order to start a time plot. During the time plot mode, the sequential measurement of all 24 channels continues as in the sequential mode.

The 24-channel Current Source Module contains the analog circuitry required to measure resistance on each of its 24 channels. The Control Module provides interface between the current source module and the refrigeration μC, generates the commands required by the current source module for resistance measurements in both the sequential and time plot modes, and provides temporary data storage for resistance measurements. In both the sequential and time plot modes, the μC can request data stored in the control module at any time, whether the data is a result of normal sequential measurement or a time plot measurement.

Design criteria of the system include 0.5% measurement accuracy, modular design, and simplification and reduction of module calibration procedures. Also, the system must be capable of measuring resistance within the specified tolerance limit at cable lengths of up to 700 feet, which is the longest distance between the electronics modules and the cryoloop turnaround box.

II. Measurement Scheme

The scheme used to measure the resistance of the temperature transducers is illustrated in Fig. 1. A constant current pulse I_g is generated and transmitted down a cable pair to the resistance thermometer R_T. The voltage V_T is sensed via a second cable pair by a differential amplifier A. If the pulse width of I_g is long enough to allow for voltage setting due to transmission line effects and cable capacitance, the resistence R_T can be calculated by measurement of V_T, if I_g is known. A two cable pair arrangement is used in order to minimize error introduced into the measurement due to series resistance of the cable. (Current into amplifier A is assumed to be negligible). The cable used in the system is Belden 8728 audio cable, which contains two individually shielded twisted pairs in a single jacket. This choice of cable requires installation of a single cable to each temperature resistor.

The current pulse generated by the current pulse module must meet constraints, limiting the power dissipation in the resistance thermometers. These constraints must be met in order to minimize measurement errors due to self-heating of the resistance thermometers as a result of power dissipation in the resistors. This is especially critical in the carbon composition resistors, whose low mass and specific heat at cryogenic temperatures make them susceptible to self-heating.

The constraints which must be met are as follows:

1) Peak current = 2.5 ma max

2) Pulse width = 50 μS max

3) Repetition period = 50 mS min.

These limits are the results of experimental data and compromise signal-to-noise ratio and voltage settling time, both of which are sources of measurement error.

III. Circuit Description

A. 24-channel Current Source (Refer to Drwg. 1680-ED-107846)

The function of the current source module is to apply a precision current pulse onto the appropriate channel (resistance thermometer), detect voltage across the temperature resistor, convert the voltage to digital data, and present that data to the control module for storage. The control module provides the channel address and commands required by the current source module to perform these operations.

The precision current pulse is generated by the 2.5 mA CURRENT SOURCE, which converts the output of a 10V PRECISION VOLTAGE REFERENCE to a constant 2.5 mA current. In the inactive state of the module, the current flows thru the SOLID STATE SWITCH to ground. When the CURRENT PULSE signal from the control module goes low, the SOLID STATE SWITCH applies the 2.5 mA current to the OUTPUT MUX. These analog multiplexers apply this current to the channel selected by the control module, as determined by the MUX ENBL and MUX ADR inputs. Note that the current flow is a negative current - this is required by the analog multiplexers of the OUTPUT MUX. A positive output current thru the multiplexers causes excessive internal current leakage in the multiplexers due to their JFET switch arrangement. When the CURRENT PULSE signal is removed, the current to the selected temperature resistor is removed.

The voltage across the selected resistor is sensed by an INSTRUMENTATION AMPLIFIER via INPUT MUX, whose address inputs are the same as those on the OUTPUT MUX. This amplifier, which has a high CMRR to minimize error due to common-mode noise and high input impedance to minimize error due to loading has a gain of 40, which causes voltage sensed across a 100 ohm resistor to beamplified to 10.0V, corresponding to the full scale input of the ADC.

Near the end of the 50 μs CURRENT PULSE signal, a HOLD signal is received for the control module. This signal causes the SAMPLE-HOLD AMPLIFIER to hold the amplified voltage during the A/D conversion. A few microseconds after the HOLD command, a CONVERT command is received from the control module, causing the ADC to convert the held voltage to digital data. The data is then loaded into memory on the control module.

The ZERO-CROSSING DETECTOR uses the 60 Hz, 120 VAC line input to generate 60 Hz NODES, a 60 Hz TTL-compatible square wave used for timing purposes on the control module.

B. Control Module (Refer to Dwg. 1680-ED-107686)

The functions of the control module are to provide the signals required by the current source module (or modules) for making resistance measurements either in the sequential or time plot mode, to store data from the current source modules in memory, and to provide interface between the system and the refrigeration µC, including readout of data and accepting time plot commands.

In its normal state, the control module operates the system in the sequential mode. At each level change of the 60 Hz NODES input U1 generates a pulse, advancing the MOD-5/6 COUNTER. In the sequential mode, the PLOT FF is not set, causing U22 to generate one positive pulse at pin 15 for every five 60 Hz NODES transition (once every 42 mS). This pulse is transmitted thru gates U3 and U14, causing a monostable to set the MEAS FF. This FF, when set, causes the TIMING CIRCUIT to generate the sequence of pulses required by the current source module for measurement of a temperature resistor.

When the MEAS FF is set, U4-11 and U6-1 enable a 1 MHz clock to advance decade counters U27 and U28. Their outputs are decoded by U29, U30, and gates U6 and U7 at 10 µs, a CURRENT FF is set, causing CURRENT PULSE/ to be sent to the current source modules via output buffer U20-3. At 58 µs, the HOLD FF is set, generating the HOLD command. At 60 µs, the CURRENT FF is reset, removing CURRENT PULSE/. At 65 µs, the CONVERT FF is set, causing CONVERT/ to start the A/D conversion on the current source modules. At 95 µs, if the µc is in the process of reading a word from memory (causing the RDBK FF to be set), gate U4-8 disables the 1 MHz clock, preventing the TIMING CIRCUIT from advancing. This ensures that data is not attempted to be written into memory while a readout is taking place. When the µC has completed the readback the RDBK FF is reset, allowing the TIMING CIRCUIT to continue operation. At 97 µs, the ADDRESS FF is set, generated MAE/. This signal inhibits the µC from reading out data from memory. At 98 µs, the WRITE FF is set, causing WE/ to load ADC DATA into memory. At 99 µs, WE/ is removed. At 100 µs, a monostable generated END MEAS, which resets the MEAS, CONVERT, and ADDRESS FF's ending the measurement sequence.

The chanel address sent to the current source modules during the sequential mode is determined by the SEQUENCE COUNTER. The output of this counter is selected by MUX 1 (since MODE is always high during the sequential mode) and transmitted thru gates U12 and output buffer U21 to the enable and address lines of the analog multiplexers on the current source modules. Note that the two MSB's of the SEQUENCE COUNTER determine the ENBL outputs and the three LSB's determine the ADR outputs. The output buffers are enabled by the MEAS FF. The CURRENT PULSE/ signal is generated 10 µs after the output buffers are enabled, allowing time for the proper channel to be selected. At the end of the measurement, END MEAS advances the SEQUENCE COUNTER when MODE is high.

The SEQUENCE COUNTER also determines the memory address in the sequential mode. MUX 2 selects the output of the SEQUENCE COUNTER when MODE is high, and MUX 3 selects the output of MUX 2 when a readout of data is not in progress. This applies the output of the SEQUENCE COUNTER to the memory address pins during the sequential mode.

The SEQUENCE COUNTER counts from 0 to binary 23, then resets ittself at the next END MEAS pulse if MODE is high. This corresponds to the 24 channels being measured by the current source modules and their 24 corresponding memory locations. As the 60 Hz NODES continue to advance the MOD 5/6 COUNTER, a new measurement is made each time the MEAS FF is set. At the end of each measurement the SEQUENCE COUNTER advances, causing the next measurement to be made on the next channel. This process continues indefinitely, with new data being written into the memory location corresponding to each channel at a rate of once per second.

To generate a time plot, the refrigeration μC must provide the control module with a channel address (the channel on which the time plot is to be performed) and a measurement time interval. This information, and all other information exchanged between the μC and the control module, is transferred using standard Multibus techniques. (Refer to Intel Multibus Specification Manual for details of the data transfer).

To start the time plot, the μC which acts as the Multibus Master, loads the PLOT ADDRESS REG with the address of the channel to be plotted. To do this, the μC addresses the control module by presenting the appropriate address on lines ADR4/-ADR7/. The PAL 14L4 (Programmable Array Logic) recognizes the address and enables the board. The ADR1/- ADR3/ lines are decoded, and the 8 decimal outputs are used to address the appropriate registers on the control module. To address the PLOT ADDRESS REG, the DS7 code must be supplied on these address lines.

With the DS7 code on the address bus and the channel address waiting on the data bus, the μC sends an IOWC/ to the control module. This causes the PAL 14L4 to send WRT/, causing data on th DBOUT lines (buffered data from the data bus) to be loaded into the PLOT ADDRESS REG. When IOWC/ is sent, the PAL 14L4 generates CMD/, enabling the 74164(U69) to shift "1's" serially into it. (The system clock shifts the data). After a short delay, a XACK/ is sent onto the system bus indicating that data was received by the control module. When XACK/ is received by the μC, it removes IOWC/, indicating that the transfer is complete. The control module then removes XACK/ (BD ENBL/ from the PAL 14L4 is active only during IOWC/ or IORC/).

Next the μC must present the sampling interval to the control module. Since the sampling interval is a 16-bit word, and the system has an 8-bit data bus, two writes must be performed. The sampling interval can range from 50 ms to 54 minutes, with all "1's" on the data bus being 50 ms interval, and all "0's" being 54 minute intervals. (The sampling interval can be any multiple of 50 ms between these limits).

To load the sampling interval, the µC first places the LSB's onto the data bus, presents the DS4 address code, and sends IOWC/. This loads the LSB's into U31. Similarly, the MSB's are loaded into U32 using the DS3 address code. When this IOWC/ is sent, the PLOT and LOAD FF's are set. The PLOT FF causes the MOD-5/6 COUNTER to go into the MOD-6 mode, generating one pulse at pin 15 of U22 for every 6 clock pulses. Gate U14-12 generates a pulse whenever QA and QB of U22 are both high (this happens twice for every pulse at pin 15 of U22, with one pulse being coincident with the pulse at pin 15). The pulses generated by U14-12 are used to set the MEAS FF for the sequential mode (this mode continues to function even during the time plot). The pulses generated by U22 are used to advance the MOD-N COUNTER.

The LOAD FF, when set, causes the next pulse from the MOD-5/6 to load data from U31 and 32 into the MOD-N COUNTER. The MOD-N COUNTER then advances at each pulse from the MOD-5/6 COUNTER until its overflow condition is reached; then the next pulse again loads the data from U31 and U32. The output of the MOD-N COUNTER (U26 pin 15) generates a pulse at each overflow of the counter. This pulse is used to set the MEAS FF for time plot measurements; it also generates MODE.

When a pulse from U14 occurs, a normal sequential measurement takes place, as described previously. When END MEAS occurs, the SEQUENCE COUNTER is advanced, since MODE is high. When the MOD-N COUNTER generates an output pulse, MODE goes low. Again, the normal sequence of events occurs for a measurement. However, MUX1 selects the output of the PLOT ADDRESS REG and uses this to select a channel for measurement. MUX 2 selects the output of the PLOT MEMORY POINTER (set to binary 24 when the PLOT FF was set) and applies it to the memory address pins via MUX3. Thus, when WE/ occurs, the first time plot data word is loaded into memory location 24. When END MEAS occurs, the PLOT MEMORY POINTER is advanced (since MODE is low). Time plot data is then stored in memory locations 24-255. Note that when gate U14 and the MOD-N COUNTER generate simultaneous pulses, the time plot measurement has priority, since MODE is low. After 232 time plot measurements have been made, the PLOT MEMORY POINTER resets to zero and generates a pulse at pin 12, resetting the PLOT FF, which terminates the time plot.

Readout procedures for sequential and time plot data are identical and can be performed at any time by the µC. Since data words are 10 bits wide, the data must be read out in two operations, with the 8 LSB's read first, followed by the two MSB's, right justified on the data bus. To read out the data, the memory address to be read (0-23 for sequential data, 24-255 for time plot data) is placed onto the data lines by the µC, the DSO code is presented on the address lines, and IOWC/ is sent. This loads the address into the READ ADDRESS REG. Next, the µC presents the DS1 code onto the address lines and sends IORC/. The PAL 14L4 genrates RD/, causing the RDBK FF to set if MAE/ is high (write cycle not in progress). If MAE/ is low, the RDBK FF is not set and XACK/ is inhibited by gate U60-13 until the write process is complete.

When the RDBK FF is set, MUX3 applies the outputs of the READ ADDRESS REG to the memory address pins. The ADR 0 line (LSB of the system address bus) selects which group of memories (corresponding to current source module 1 or 2) is enabled. The outputs of the appropriate memories are placed on the system data bus via the OUTPUT MUX and the data bus transceivers. After a short delay XACK/ is generated, causing the μC to receive the data and remove IORC/. This completes transfer of the 8 LSB's of the data word.

In a similar fashion, the μC reads the MSB's of the data word, (if a write cycle is not in progress) by presenting the DS2 address code and sending the IORC/. The 2 LSB's are transferred to the μC. When IORC/ is removed, a monostable advances the READ ADDRESS REG by one count. This feature simplifies the operations for a block transfer of data, since the μC is not required to write a new read address into the READ ADDRESS REG for each data word.

The μC can read out time plot data, even if a time plot is incomplete. In order to read out only valid data, the μC can read the contents of the PLOT MEMORY POINTER to determine how much of the memory contains recent data. To do this, the μC presents the DS5 address code and sends IORC/. The OUTPUT MUX places the contents of the PLOT MEMORY POINTER onto the data bus, and XACK/ is generated. The μC can then read valid data from memory locations 24 to one less than the contents of the PLOT MEMORY POINTER. If the contents are zeros, the time plot is completely finished.

The μC can also read back the contents of any register on the control module which it can write into. The READ ADDRESS REG, MOD-N COUNTER MSB's, MOD-N COUNTER LSB's, or PLOT ADDRESS REG can be accessed by presenting the DS0, DS3, DS4, or DS7 address codes, respectively, and sending IORC/. This feature is useful for fault-checking of the system data bus and the control module.

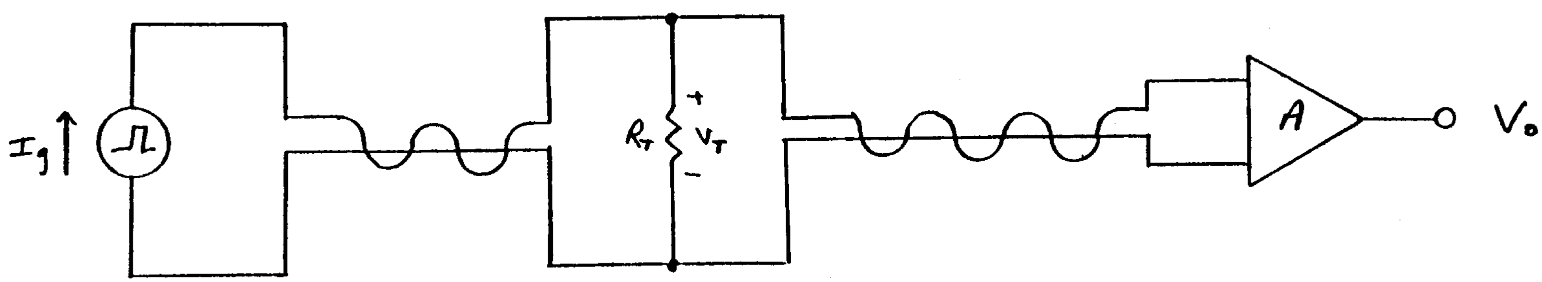
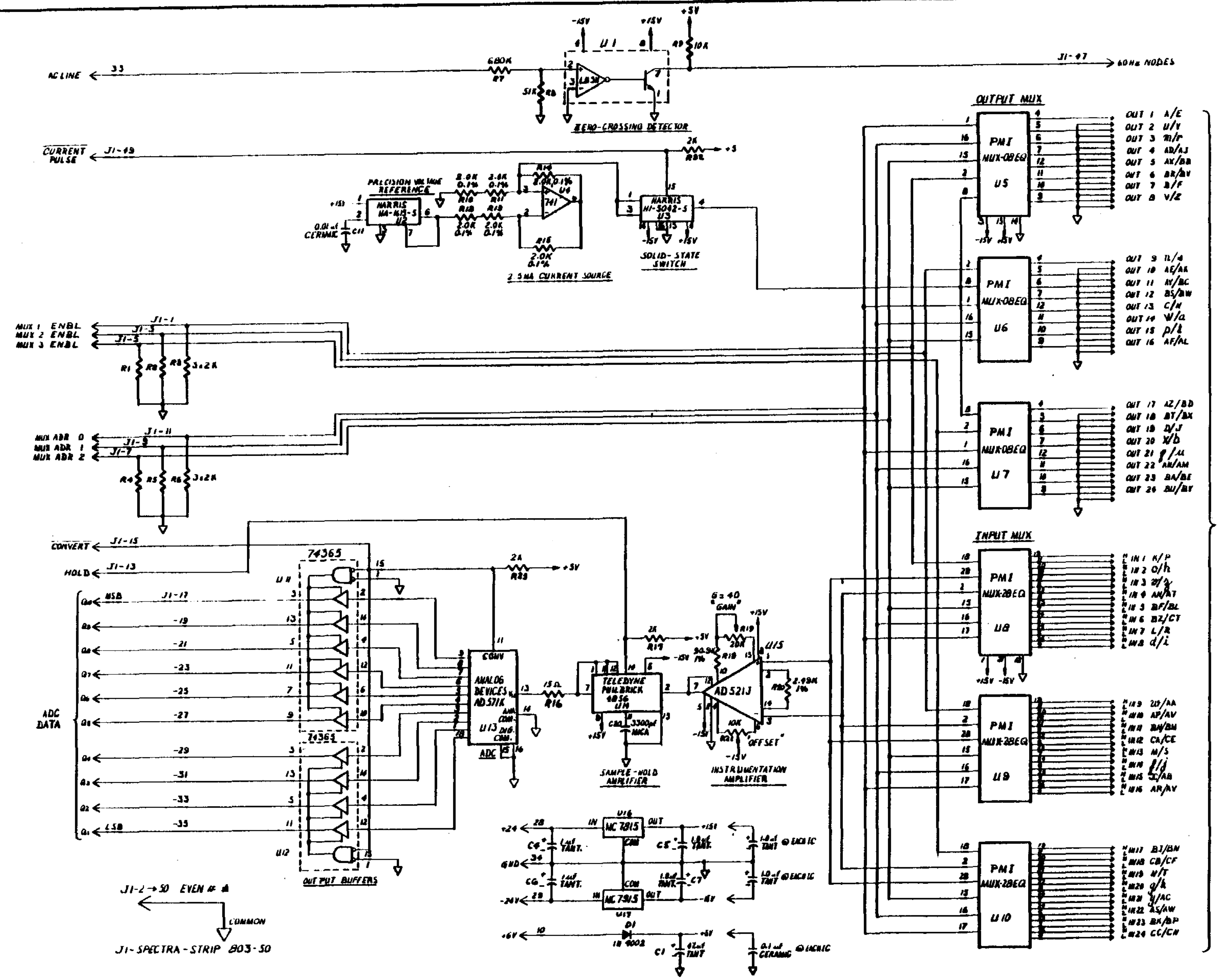


FIG. 1: RESISTANCE THERMOMETER MEASUREMENT SCHEME.



REV.	DESCRIPTION	DRAWN / APPD.	DATE
A	REVISE PER MARKED COPY	HERRMANN / D. Howard	6-19-81 / 6-19-81

ITEM NO.	PART NO.	DESCRIPTION OR SIZE
	SILKSCREEN	BD-158014
	SOLDER MASK	BD-158015

PARTS LIST

ORIGINATOR	G. PUCCI	5.13.80
DRAWN	TONUS R SENGMANNING	2.12.81
CHECKED	D. Howard	
APPROVED		

USED ON

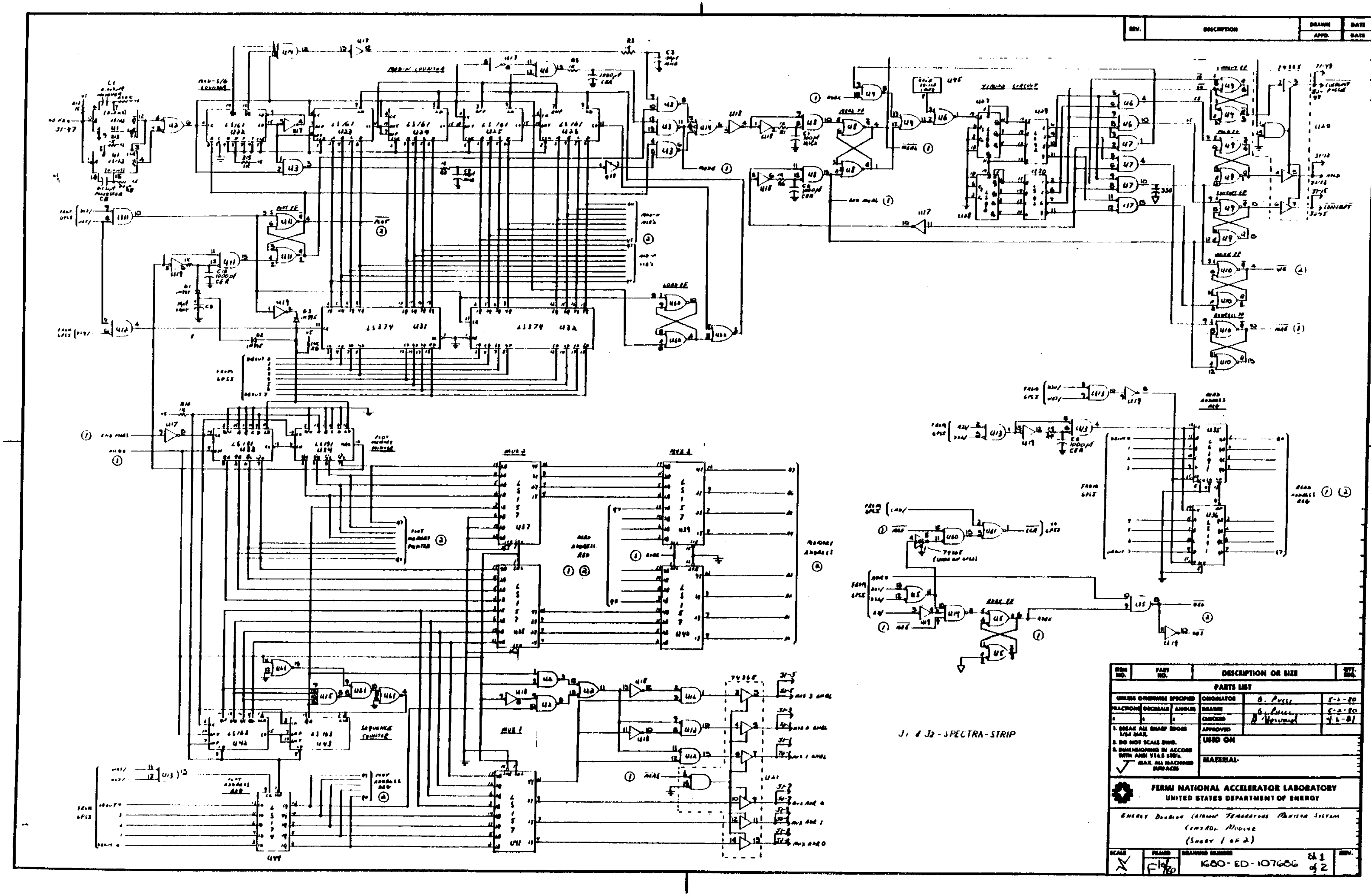
MATERIAL-

1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH ANSI Y14.5 STD'S.

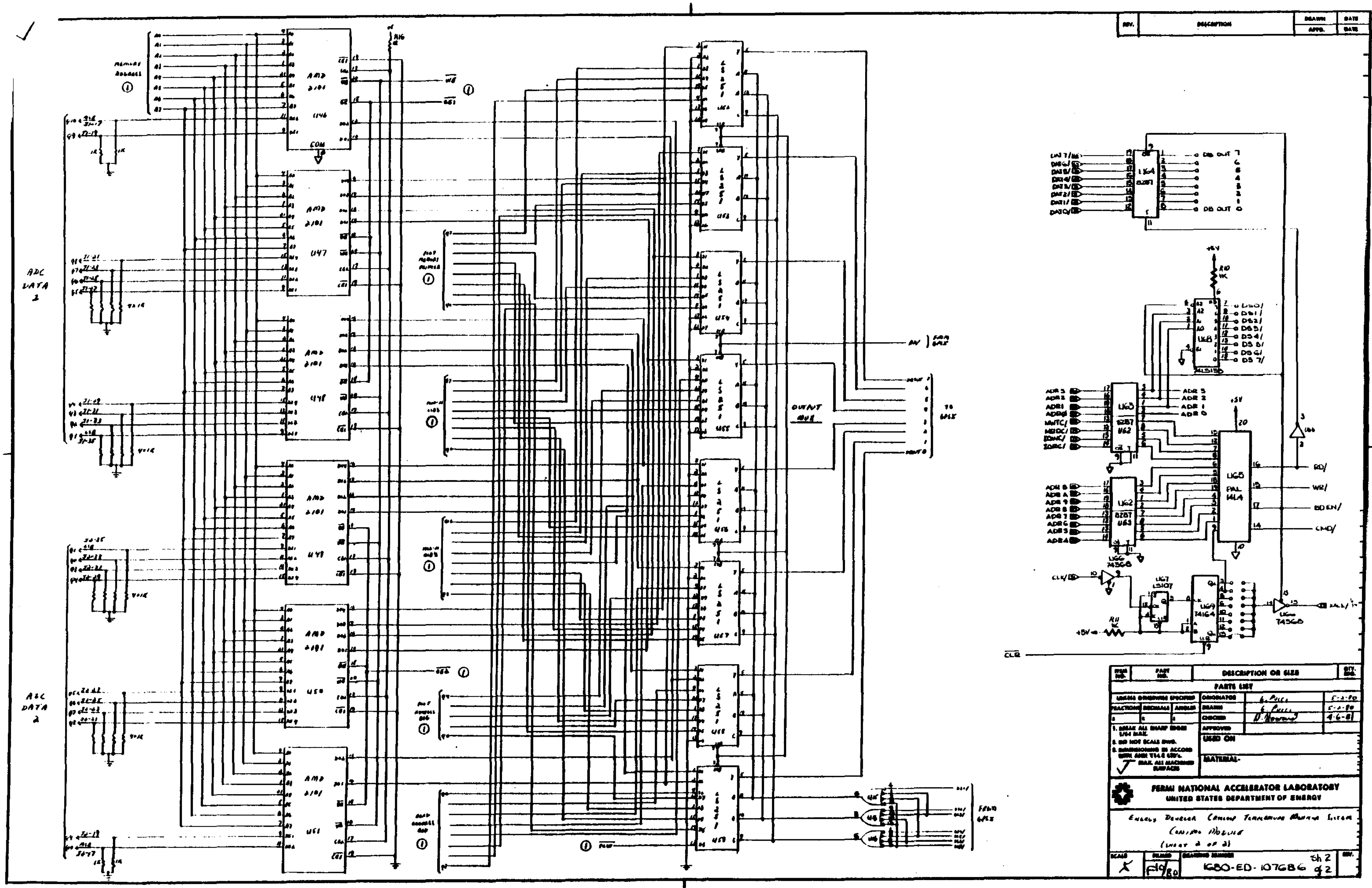
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

ENERGY DOUBLER
CRYOLOOP TEMPERATURE MONITOR
24 CHANNEL CURRENT SOURCE

DRAWING NUMBER: 1680.00-ED-107846 REV. A



MOD-N COUNTER
TIMING CIRCUIT
LS161
LS374
MUX 2
MUX 1
PLOT MEMORY POINTER
READ ADDRESS REG
MEMORY ADDRESS
SEQUENCE COUNTER
PLOT ADDRESS REG
READ ADDRESS MUX
J1 & J2 - SPECTRA-STRIP
DESCRIPTION OR SIZE
PARTS LIST
UNLESS OTHERWISE SPECIFIED
FRACTIONS DECIMALS ANGLES
1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH ANSI Y14.5 STD's.
MAX. ALL MACHINED SURFACES
ORIGINATOR 5-1-80
DRAWN 5-2-80
CHECKED 4-6-81
APPROVED
USED ON
MATERIAL
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
Energy Doubler Cryogenic Temperature Monitor System
Control Module
(Sheet 1 of 2)
SCALE
DRAWING NUMBER
1680-ED-107686
Sh 1 of 2
REV.



MEMORY ADDRESS
ADC DATA 1
ADC DATA 2
AMD 2101
U46
U47
U48
U49
U50
U51
COM
WE
OE1
OUTPUT MUX
TO 6PLX
FROM 6PLX
OE2
U64
8287
DB OUT 7
DB OUT 0
U68
74LS138
U63
U62
8287
U65
PAL
14L4
RD/
WR/
BDEN/
CMD/
ADR 5
ADR 2
ADR 1
ADR 0
CLK/
U67
LS107
U69
74164
74S68
CLR
R10
R11
R16
+5V
DESCRIPTION OR SIZE
PARTS LIST
ORIGINATOR
DRAWN
CHECKED
APPROVED
USED ON
MATERIAL-
5-2-80
5-2-80
4-6-81
FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY
SCALE
DRAWING NUMBER
1680-ED-107686
Sh 2 of 2